A NEW STEREO FEEDBACK CUTTERHEAD SYSTEM

by

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AUDIO

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A NEW STEREO FEEDBACK CUTTERHEAD SYSTEM

by

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I. INTRODUCTION

A little over a year ago, our thinking was directed toward the design of a Stereo Disc Recording System. It was then rumored that both Westrex as well as British Decca were actively engaged in developing such systems, but by most people these remarks were met with skepticism. Little did we know that only a little more than a year later the entire industry would accept Stereo Disc as a reality. After preliminary investigations, we went into active development of a New Stereo Disc Recording System.

II. DESIGN OBJECTIVES

The following objectives were set up for the Stereo Cutter System:

A. To record amplitudes up to 6 mil peak-to-peak, at frequencies from 20 to 500 cycles, and velocities in excess of 30 cm/sec. between 1 kc and 3 kc, and in excess of 14 cm/sec. from 3 to 15 kc.

B. To meet the objectives set up in "A", with total harmonic distortion not exceeding 1%, including all harmonic components to 15 kc.

C. To obtain a frequency response flat within ± 3 db from 20 cycles to 15 kc and separation in excess of 20 db.

D. To meet points "A", "B", and "C" in both stereo channels as well as the lateral plane.

E. To maintain stability of level, frequency response and distortion independent of lacquer loading, temperature, or aging.

F. To provide a simple, rugged unit with a minimum of parts and no critical adjustments so as to make possible repairs and replacements in the field.

G. To supply a complete system, complete with amplifiers, equalizers, monitoring and switching facilities in one package, ready to be fed from an audio source.

III. DESIGN

A. Type of System and Basic Design

In order to meet the objectives set forth in the previous paragraphs, the two known principles of cutter operation were investigated.

The moving iron system was looked at first, but it is known that moving iron systems are essentially in unstable equilibrium as the actual motion of the armature will always be more than predicted by the change of flux. This condition becomes further aggravated at large amplitudes, producing a great deal of odd harmonic distortion, principally third. In order to reduce this distortion very stiff mechanical systems have to be used in addition to long gap length, which adds another form of distortion caused by the near saturation flux densitities in the armature. These reasons disqualify moving iron systems within the design objectives outlined.

Our efforts were then concentrated on the moving coil system. To meet objective "F", the Cutter should have no linkages, so a single armature system was decided upon, actually a single coil form holding two independent windings for the two orthogonal channels.

Contrary to moving iron systems, the stiffness in a moving coil unit can be comparatively low and the resonant frequency is usually placed near the middle of the audio spectrum. Moving coil systems are inherently linear, assuming a homogeneous flux field within the limits of motion.

To analyze the performance of such a moving coil system, two adaptations of the basic motor force formula were derived:

For the inertia-controlled region

$$e\,i = 50\left[\frac{V\,\omega\,M}{B\,l}\right]^2 Z$$

For the stiffness-controlled region

$$e\,i = 50\left[\frac{D\,\omega_0^2\,M}{B\,l}\right]^2 Z$$

Where

e = RMS volts
i = RMS amperes

V = peak velocity in cm/sec.
$\omega = 2\pi f$
$\omega_o = 2\pi \cdot 1200$ (resonant frequency)
f = frequency in cycles/sec.
M = mass in grams
B = flux density in gauss
l = total active length of wire in motor coil in cm.
Z = impedance of winding in ohms

From these basic formulas, optimum armature dimensions were derived. Flux density in the gap was assumed to be 10,000 gauss, l = 254 cm, M = 2 grams, Z = 5 Ω at 100 cycles/sec. and 9.2 Ω at 10 kc, giving

32 VA for 6 mils peak-to-peak amplitude, at any frequency from 20 cycles to 500 cycles

47 VA for 14 cm/sec. at 5 kc

220 VA for 14 cm/sec. at 10 kc

At mid-frequencies, where most of the program power is concentrated, very little driving power is required,

.03 VA for 7 cm/sec. at 1 kc

Within the framework of the accepted 45-45 system, one can transpose the two input signals to vertical-lateral by the well-known sum and difference method in order to operate on these components in the prescribed way, and then either re-transpose to 45-45 to feed a 45-45 cutter, or directly feed a vertical-lateral cutter. The latter method was chosen since it facilitates the design of the magnetic circuit and the armature, and makes the cutting of pure lateral or vertical free of precise channel balancing.

B. Magnetic Circuit

The dimensioning of the armature, to provide the desired sensitivity in the mass-controlled region based on a flux density of 8 to 10 kilogauss, defined the gap structure as .080" long by .125" wide by 11/16" deep. Given this four-gap structure and the space above the plane of the recording disc in which to place the magnets and pole pieces it becomes, in essence, a matter of supplying flux between two diagonally placed north poles and two diagonally placed south poles. Several attempts to do this with a single magnet failed due to the need for crossing over the pole pieces to get to the appropriate pole faces, with resultant high leakage, near saturation flux densities, long path, and right-angle bends.

It is generally accepted practice when one desires high flux densities in an air gap to use tapered pole pieces so that the progressively higher net leakage flux, as one moves away from the gap toward the magnet,

is fed through a progressively larger pole piece cross-section to avoid saturation and also to get down in flux density to a level at the magnet face suitable for the magnet itself, whose saturation level generally is less than one-half that of good pole-piece material.

In order to avoid the crossing over in the magnetic circuit, the use of two separate magnets to feed the four gaps seemed to be indicated. Then by making judicious use of the available 180° space above the disc for tapered pole pieces and tapered leakage paths, a rather compact pole structure resulted. The pole pieces are tapered both in thickness and width and are fed from horseshoe magnets. In the design of a magnetic circuit an oversimplified but useful procedure is to substitute in Eq. (1) the known dimensions and the estimated values for the leakage factor F and reluctance factor f to obtain the value of B_d/H_d.

$$\frac{B_d}{H_d} = \frac{F}{f}\,\frac{A_g}{A_m}\,\frac{L_m}{L_g} \qquad (1)$$

B_d/H_d defines the operating point on the demagnetization curve of the particular magnet material used.

F = leakage factor
f = reluctance factor
A_g = area of gap face
A_m = area of magnet face
L_g = length of gap
L_m = length of magnet
B_g = flux density in the gap

The ratio B_d/H_d is then applied to the demagnetization curve of the magnet material (e.g., Alnico V) to obtain the value B_d. B_d is then substituted in Eq. (2) to obtain the flux density in the gap.

$$B_g = B_d\,\frac{A_m}{F \cdot A_g} \qquad (2)$$

Fig. 1 is a plot of flux density in the gap vs. the leakage factor for this magnetic structure and illustrates the pitfalls of underestimating the leakage. The only substitute for clairvoyance in a magnetic circuit problem is careful calculation and/or seemingly endless experimentation. We indulged in some of both.

The flux density in the gaps was predicted at 9.1 kilogauss and the first model of this design gave 8.7 kilogauss. Refinements in processing have since raised the flux density to over 10 kilogauss. There is some inequality in the two vertical gaps due to the unbalanced

leakages. This inequality can readily be eliminated by the addition of a third magnet of appropriate length and cross-section, should this prove to be desirable, with some increase in total flux. The flux density achieved is entirely adequate to provide the desired sensitivity for the Cutterhead. Fig. 1A shows the magnetic circuit.

C. Armature

As previously discussed, the armature had to meet certain mechanical and electrical requirements in order to conform to design objectives. Since the calculations in III. A. indicated that 220 VA would be required at 10 kc to provide 14 cm/sec. peak recorded velocity, it was obvious that a new approach had to be found to reduce this power requirement. It was felt that a secondary resonance involving a less than infinitely stiff armature could substantially increase the sensitivity at high frequencies. This approach was followed. The measured power requirement, benefited by the secondary resonance, proved to be 36 VA at 10 kc, bringing it in line with other parts of the spectrum. The frequency response is shown in Fig. 2.

In attempting to design the optimum armature, a good number of practical difficulties were encountered. Most of the motions are small in amplitude and, being high in frequency, are very difficult to observe, so a good number of cut-and-try operations had to be followed, including the making of a large scale approximation (4 feet tall) of the lumped constants. This indicated the importance of making the pivot as short as possible and moving it as close as possible to the rear end of the armature. Due to the high level of power dissipated in the armature, materials had to be chosen to withstand up to 500° F. Ceramic insulated wire wound on an anodized aluminum bobbin impregnated with high-temperature silicone varnish fulfilled these requirements. The armatures have withstood all kinds of abuse without breakdown.

D. Feedback System

Before choosing the motional feedback means actually used in the Cutter system, most of the usual transducers were considered and some were tried out. Of the velocity-sensitive methods, the magnetic types are subject to unwanted inductive pickup from the two motor coils, low sensitivity, and are rather delicate structures; the DC capacity types, although perhaps theoretically linear, are in practice nonlinear, insensitive, subject to undesired static field pickup, DC leakage with humidity, and difficult to cable. Of the well-known displacement-sensitive methods, the RF capacity type suffers from most of the difficulties of the DC capacity type, particularly stray fields and nonlinearity. The Piezo electric types are so difficult to harness mechanically as to be not worth considering. All of the

above involved the addition of some undesirable mass to the armature.

There is considerable merit in the use of a displacement responsive feedback pickup in a Cutter system because the region of the audio spectrum requiring feedback the most is in that region below its mechanical resonance where the Cutter is stiffness-controlled, since it is only in this region that the lacquer loads the stylus appreciably, this loading being nonlinear. Since the Cutter is constant amplitude in this region, an amplitude pickup can provide feedback control down to the lowest program frequencies, for example, in this case, 10 db to below 15 cycles.

The feedback system used in the Cutter is a novel RF system, having none of the defects of previously-known RF systems. It is amplitude responsive, provides high level output with low noise, is extremely linear, and involves no critical tuning or balance conditions. It consists, in essence, of a variable inductance balanced transducer; transformer-coupled bridge circuit; amplitude-stabilized RF oscillator; and differential detector. It is not a frequency modulation and detection system and does not depend for proper operation on the frequency stability of the oscillator or the associated circuitry. No mass need be added to the armature for the pickup feature, although for convenience we have added small disc which increase the mass by a few tenths of a per cent.

The detected transducer output is fed to a modest gain 3-stage amplifier which has its own heavy feedback, in the order of 36 db for frequencies below 500 cycles. The internal feedback frequency response of this amplifier is tailored to provide an overall feedback amplifier response, such that the system within the motional feedback loop will be constant amplitude below 500 cycles and constant velocity above 500 cycles.

In addition to the motional feedback, a small amount of selective overall electrical feedback is used to control the response of the system above the audio band.

E. Amplifier

As can be seen in the circuit diagram, the amplifier is rather conventional-looking with a few exceptions. New ceramic output tetrodes are used. These tubes, even though half the size of 6L6s, are capable of approximately 1000 watts in Class B. The 4X250B Eimac tubes in this amplifier are used strictly in Class A, giving phenomenally low distortion.

Fig. 3 shows the intermodulation distortion curve of this amplifier, indicating the lack of distortion at both low and high power levels.

Since in the recording application the driving of an inertia-controlled cutterhead requires the greatest power at high frequencies, the amplifier also should have very low difference tone distortion. This unit meets this requirement quite well, having less than 1% of the first-order difference tone at 100 watts and no higher order difference tones. At 200 watts, the first-order difference tone was .4%, the second .6%.

The second somewhat unconventional feature of this power amplifier is an extremely stiff power supply. Silicon rectifiers are used throughout and power transformers are built for minimum copper losses.

Here is a brief description of the amplifier. Only the lateral circuit is described, as the vertical circuit is identical except for the metering resistors. The input is first passed through the R101 1 db-per-step attenuator to T101. The RIAA equalization takes place in the network between the secondary of the transformer and the grid of the V101. This secondary also feeds the metering circuit S301A and V301. To correct for deficiencies in the Cutterhead frequency response, the equalization is placed in the cathode of V101. V101 is coupled to V102A, and both the electrical as well as the motional feedback are returned to the cathode of this tube. V102A is directly coupled to the grid of V102B, the latter being a split-load phase inverter. This, in turn, is RC-coupled to the driver stage V103A and V103B. The driver stage is coupled through a phase-shift network to the output stage grids V104 and V105. Two auxiliary feedback loops are connected to the cathodes of the output and the driver stage, respectively. An additional phase corrective feedback network is coupled from the plate of the output tube to the grid R140, R141, C115, and C116. The output stage is a conventional plate-loaded tetrode amplifier utilizing 4X250B ceramic tubes. The output tubes are cooled by a small centrifugal blower. (Fig. 4 applies to the above paragraph).

Contrary to most high-power amplifiers, these tubes work entirely in Class A. Since they are required to deliver a maximum of 200 watts, and since they have a plate dissipation rating of 250 watts each, these tubes, which are manufactured by Eitel-McCullough, have demonstrated their remarkable ability to withstand severe overloads and to this date we have not been able to damage a single tube.

The power supply consists of two center-tapped silicon rectifier supplies, the low voltage supply consisting of T402, CR403A and CR403B, L402, C406 and C407. This supply furnishes plate voltage for the entire Beta (motional feedback) Amplifier as well as the early stages of the Recording Amplifier and the screen voltage of the output stages. For the high voltage supply, a second center-tapped rectifier is used—T401, CR401 and CR402, L401, and C401. The high voltage supply is actually in series with the low voltage supply so as to make the voltage additive. A low voltage silicon rectifier is used to furnish DC filament voltage to the Beta Amplifier.

IV. CONCLUSION

Since the Cutter System is comprised of components described separately in this paper, it is only normal to conclude by considering the results of these components working together. Fig. 5 shows the overall frequency response of the Cutter System. This is well within the objectives set forth. All other objectives were also met in a practical unit, including separation in excess of 20 db up to 8 kc. Above 8 kc, the separation ranged from 18 to 6 db. This, however, in no way detracted from excellent aural separation. On the other hand, all of the velocities were met with over 6 db of power to spare, representing the margin of 150 watts to take care of unusually high peaks.

The prime reason for disc recording is not the recording of sine waves but the complex waveform of sound. In the final analysis, a system of this complexity, involving both the Cutter and the Playback System, can only be judged by a thorough subjective listening test. The combination of the FAIRCHILD 641 Cutter System and the FAIRCHILD 232 Moving Coil Stereo Pickup provided an experience in frequency response, dynamic range, spatial perspective, and distortion-free reproduction entirely new to our ears.

The authors hope that this system will materially advance the art of stereo disc recording.

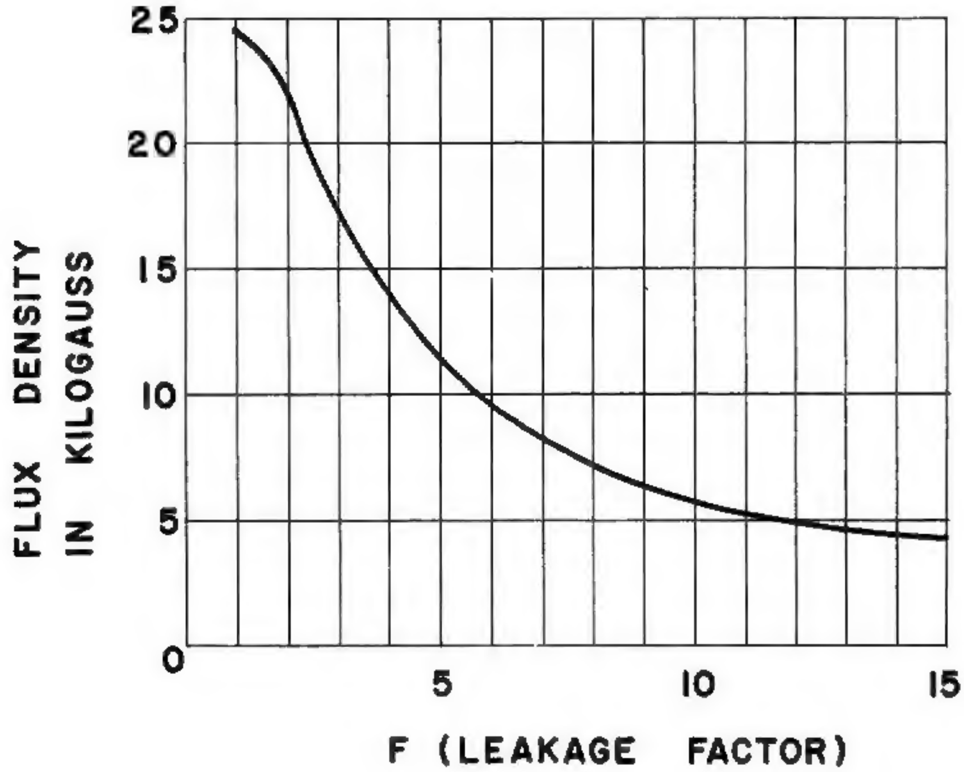

FLUX DENSITY IN KILOGAUSS
0
5
10
15
20
25
F (LEAKAGE FACTOR)

FIG. 1

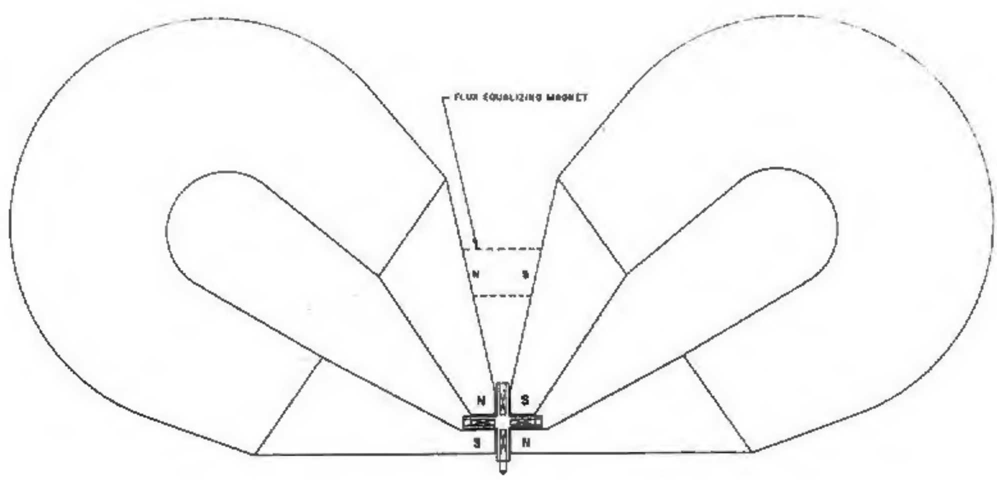

FLUX EQUALIZING MAGNET
N
S
N
S
S
N

FIG. 1A

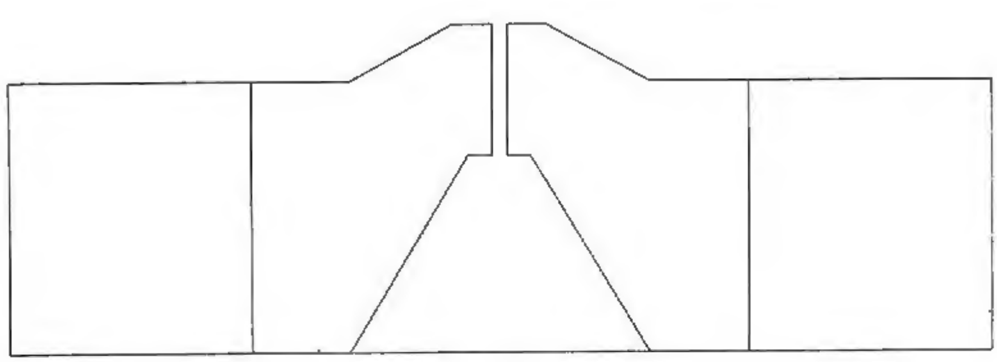
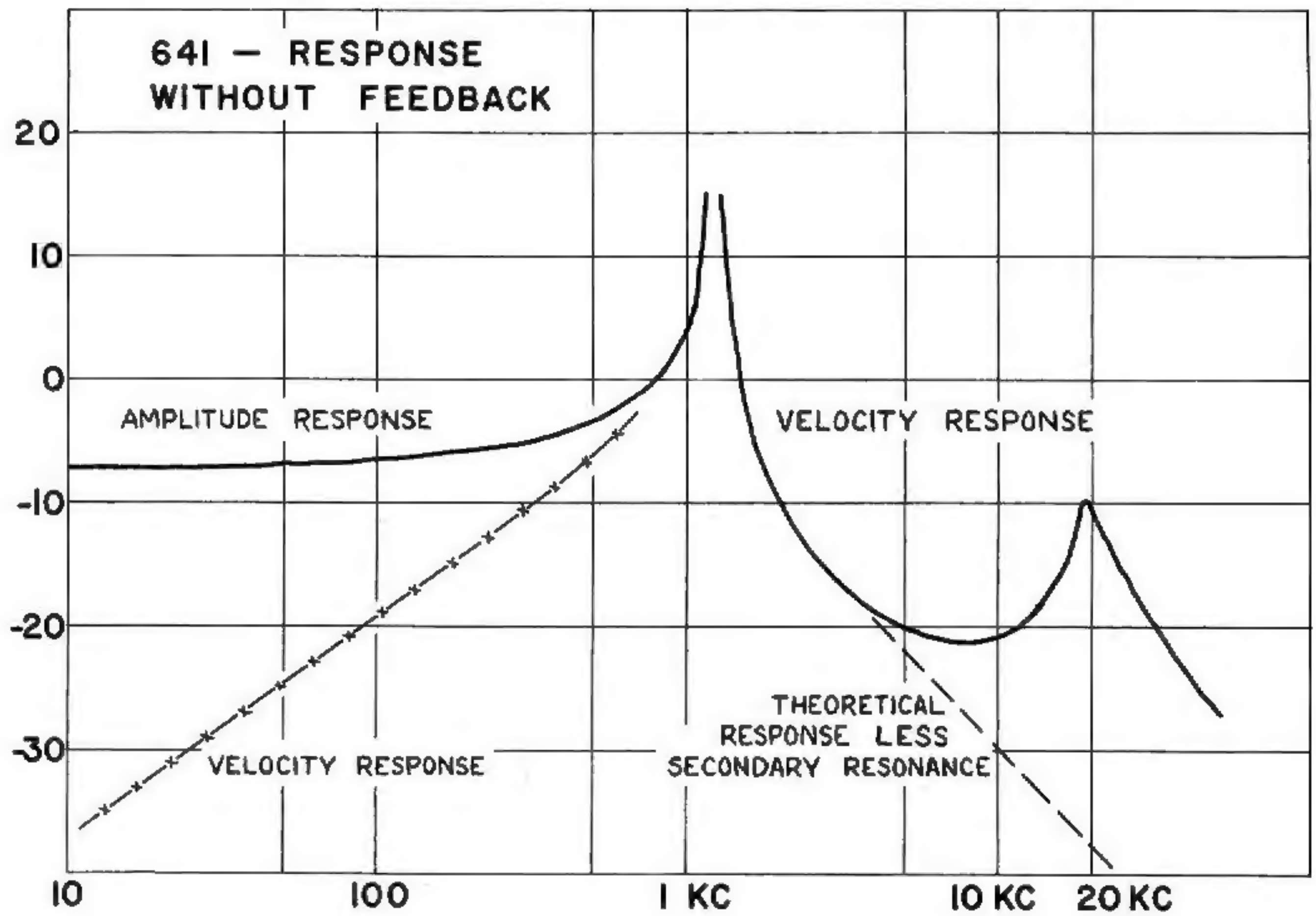


FIG. 2


641 — RESPONSE
WITHOUT FEEDBACK
20
10
0
-10
-20
-30
AMPLITUDE RESPONSE
VELOCITY RESPONSE
VELOCITY RESPONSE
THEORETICAL
RESPONSE LESS
SECONDARY RESONANCE
10
100
1 KC
10 KC
20 KC

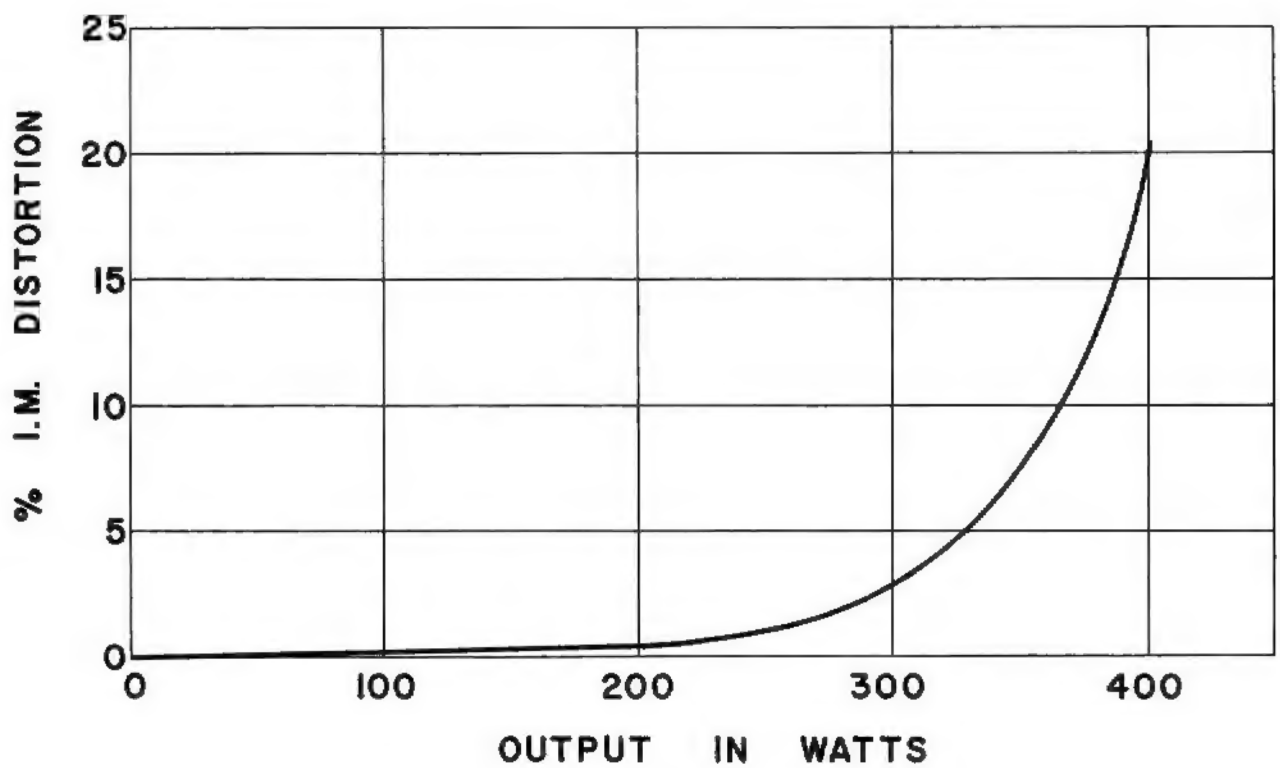

% I.M. DISTORTION
25
20
15
10
5
0
0
100
200
300
400
OUTPUT IN WATTS

FIG. 3

641 - COMPLETE SYSTEM WITH FEEDBACK

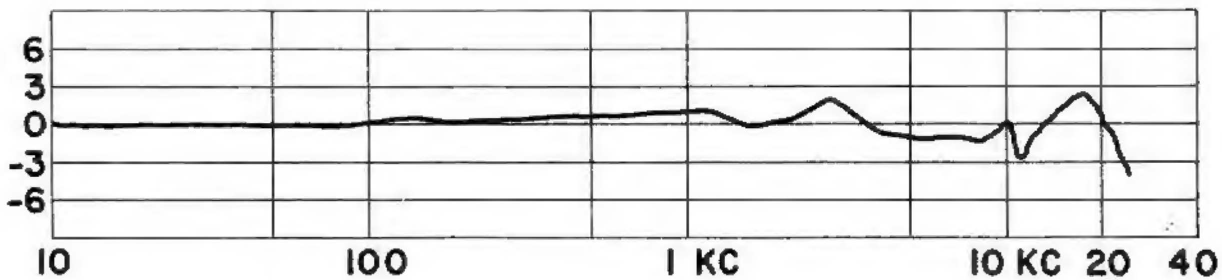


FIG. 5

FAIRCHILD STEREO DISK CUTTING SYSTEM MODEL 641

OUTSTANDING FEATURES

DESIGNED FOR THE JOB
The FAIRCHILD 641 is the first CUTTERHEAD designed from ground up for cutting 45/45 STEREO DISKS. It is not a compromise design using complex levers and couplings.

2UNITS IN ONE
The FAIRCHILD 641 is an excellent STEREO CUTTER and it also doubles as a LATERAL CUTTER capable of cutting high–level, high–quality Monophonic Disks.

EXTREMELY RUGGED AND RELIABLE
The FAIRCHILD 641 solid, one–piece aluminum, armature with high–temperature windings and impregnation has proved to be a reliable performer — nothing to go out of adjustment — nothing to burn out.

MODERN AMPLIFIER
The FAIRCHILD 641 is first in using modern all–ceramic tubes in the recording field. Two rugged high–power amplifiers on one chassis work entirely in Class A with minimum distortion, yet are capable of supplying high demands of peak–power.

HIGHER LEVEL RECORDS
The FAIRCHILD 641 is capable of producing louder records consistently — day in and day out.

LESS DISTORTION
The FAIRCHILD 641 system, being feedback–controlled over a wider frequency range, produces less distortion.

BETTER SEPARATION
The FAIRCHILD 641 has better separation, especially at higher frequencies, where separation is most needed.

FLAT FREQUENCY RESPONSE
The FAIRCHILD 641 system will maintain a flat frequency respoase from 30 to 15,000 cycles.

NO FLOATING STEREO IMAGE
The FAIRCHILD 641 will maintain the original spatial distribution of sound because of very close phase–shift equality between the two channels.

NEW FEEDBACK MONITOR
The FAIRCHILD 641 provides convenient and accurate monitoring while cutting through the amplified voltage from feedback pickups placed near the stylus chuck.

EASIER TO USE
The FAIRCHILD 641 comes complete with pre–emphasis networks for either RIAA or pop records. Variable roll–off is also provided to reduce the vertical component at low frequencies. The CUTTERHEAD can be mounted on either SCULLY, NEUMANN, FAIRCHILD, or PRESTO lathes. Convenient heating arrangement, suction tube, and advance ball make it easier to use.

DESCRIPTION

The FAIRCHILD MODEL 641 STEREO CUTTER SYSTEM is an entirely new design, unique with FAIRCHILD, and provides the means of mastering unsurpassed STEREO DISKS or, if desired, excellent lateral disks as well. It consists of three principal components in its basic form: the CUTTER itself, the DUAL-CHANNEL POWER AMPLIFIER with power supply, and the FEEDBACK AMPLIFIER. All interconnecting cables with plugs are also provided.

The CUTTER itself is designed around a compact and extremely rigid one-piece nonferrous armature which carries two moving coils wound directly on it. Because of the balanced design of the armature and the way in which the coils are wound, it has been possible to eliminate practically every trace of spurious motion and the CUTTER, without feedback, provides an exceptionally smooth characteristic. With feedback, the frequency response is good within ± 2 db from 30 cycles to 15 kc. Transient response is excellent and level handling ability allows a great reserve: in the constant amplitude region a peak-to-peak amplitude of 6 mils can be cut, from 1 kc to 4 kc a velocity of 60 cm/sec., above 4 kc a velocity of 30 cm/sec. Because of its simple and rugged design, this CUTTERHEAD can give long and trouble-free service without danger of burnout or mechanical damage.

An entirely new system of MOTIONAL FEEDBACK has also been perfected for use with this CUTTER. It is a variety of amplitude sensitive proximity pickup and imposes no loads or reaction of any kind upon the driving coils. The feedback pickups are placed very close to the stylus chuck, making the feedback voltage an exact replica of stylus motion. This enables a wide effective range of feedback control and excellent linearity throughout the useable frequency range.

The POWER AMPLIFIER utilizes a pair of 4CX250B ceramic tubes in the output of each channel. These tubes deliver 200 watts of power in Class A operation to each channel, which assures an ample reserve of power for any instantaneous requirement. The tubes are capable of over 500 watts per pair and hence are not driven hard. Every part of the amplifier is designed with due regard for the requirements of continuous operation, assuring long and trouble-free operation. All parts are instantly available for servicing when needed, and metering is provided for strategic circuit points.

The 641 SYSTEM is sold only as a complete package, for only in this way can the full performance and operating convenience designed into it be realized. All that is necessary is to connect the output of the tape machine or other program source to the amplifier, and to provide a lathe and disk at the other end. All other steps, including amplification, equalization, and cutting are provided by the 641 CUTTER SYSTEM. Mechanically the CUTTERHEAD can be mounted on most standard lathes – SCULLY, NEUMANN, FAIRCHILD, or PRESTO.

We are convinced that the 641 STEREO DISK RECORDING SYSTEM is the best to be had anywhere in the world. We therefore invite you to send us your most difficult tape of which we will gladly cut an acetate to prove to you the performance of our unit.

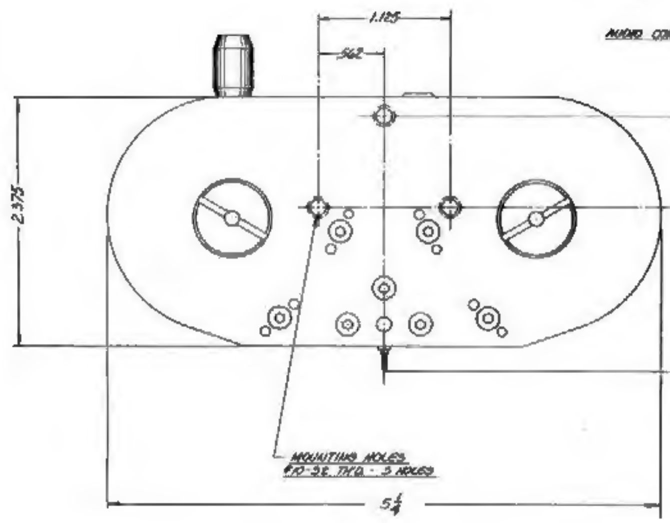
SPECIFICATIONS (Each channel, unless otherwise specified)

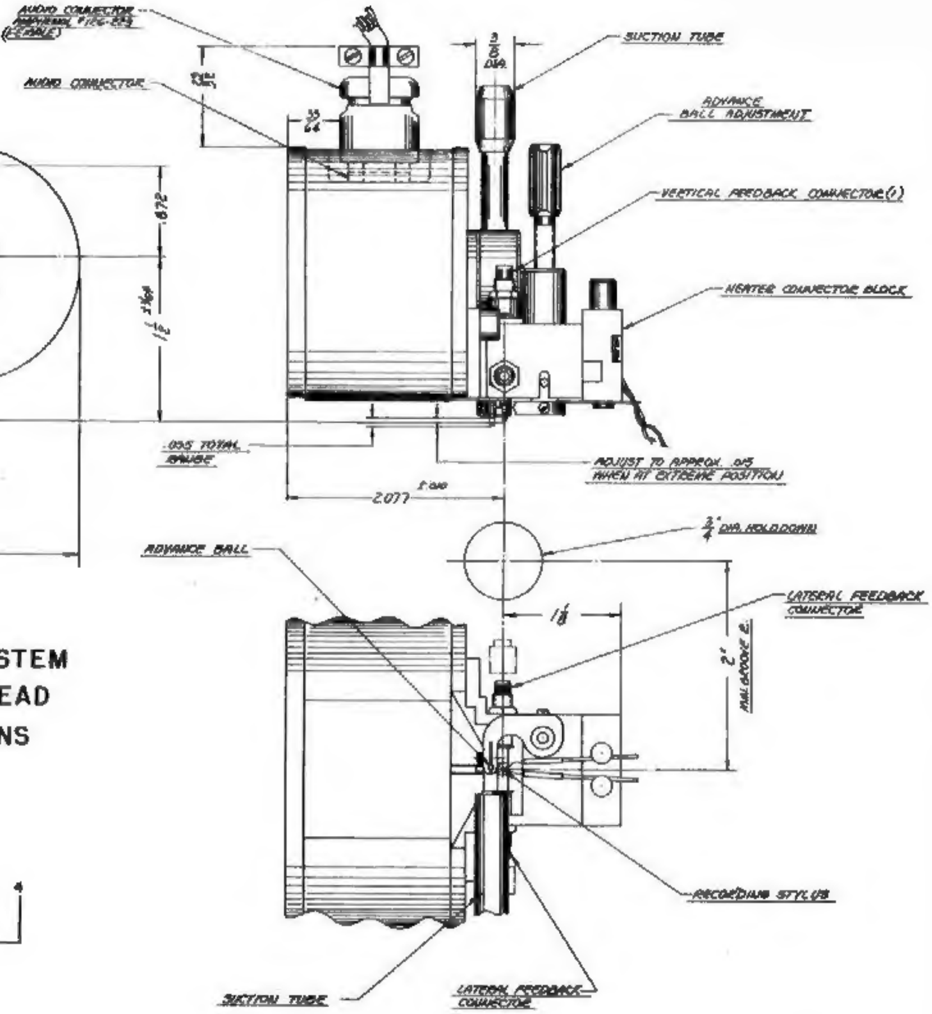
INPUT IMPEDANCE	600 Ω
INPUT LEVEL REQUIREMENTS	–16 dbm to + 8 dbm for 7 cm/sec.
INPUT ATTENUATORS	20 steps 1 db/step
FREQUENCY RESPONSE[1])	± 2 db 30 cycles to 15 kc (see graph for typical response).
CHANNEL–TO–CHANNEL SEPARATION[2])	Better than 20 db 20 cps to 10 kc. Better than 15 db 10 kc to 15 kc. In excess of 30 db at midfrequencies.
TOTAL RMS HARMONIC DISTORTION[2])	Less than 0.5% at 14 cm/sec. (1 kc to 15 kc), and at 2-mil amplitude (30 cps to 1 kc).
DIFFERENCE TONE INTERMODULATION[2])	Less than .15% 14 kc and 14.05 kc at 30 cm/sec.
VERTICAL TRACKING ANGLE	20° ± 1°
STYLUS	Tapered shank (heated)
POWER REQUIREMENTS	115 V 10 A (220/230 V also available).
MECHANICAL FEATURES	Suction nozzle, advance ball, and stylus heat attachment are permanent parts of the cutterhead.
INSTALLATION	The unit is self-contained, no wiring except input and monitor leads required. Fairchild supplies all plug-in interconnect cables.
MECHANICAL DIMENSIONS	Cutterhead: Standard 1-1/8" centers (see outline drawing). Adapters available for most cutting lathes. Power Amplifier: Standard 19" rack mounting, 17-1/2" vertical rack space, 11" depth behind panel. Power Supply: Standard 19" rack mounting, 14" vertical rack space, 11" depth behind panel.
WEIGHT	Cutterhead 3-1/2 lbs. Power Amplifier, Power Supply, and Beta Amplifier approximately 300 lbs.
PRICE	$6,650.00
TERMS	1% 10 days, net 30, f.o.b. Long Island City, New York. (Special terms may be arranged).
DELIVERY	2 to 8 weeks after receipt of firm order.

NOTE: 1) Measured by light-pattern.
2) Measured at the output of feedback monitor.

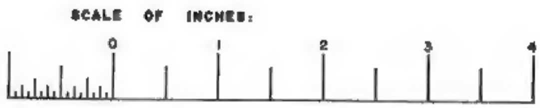
FAIRCHILD RECORDING EQUIPMENT CORPORATION
10-40 45TH AVENUE
LONG ISLAND CITY 1, NEW YORK

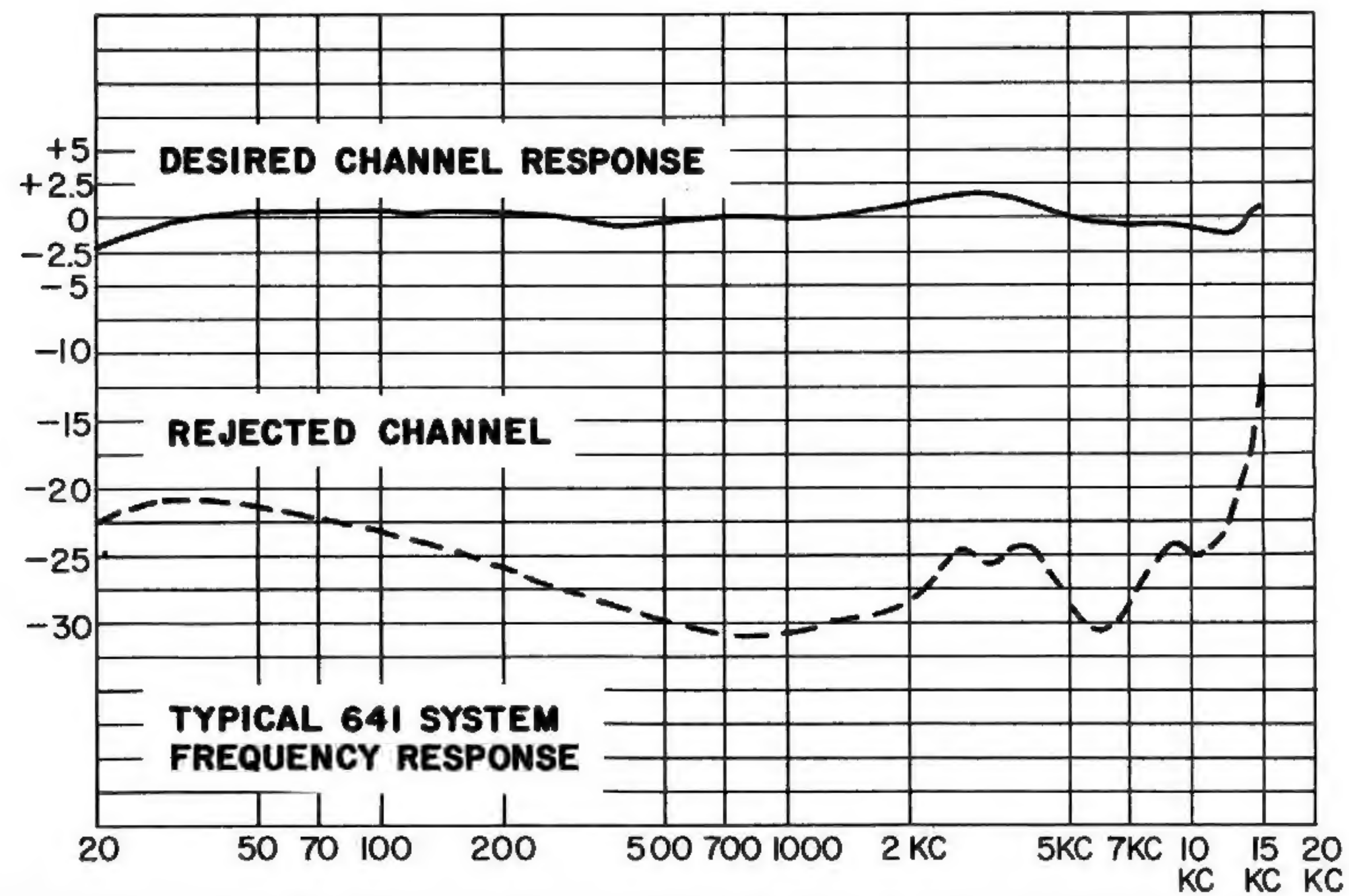
DS-641-959-1



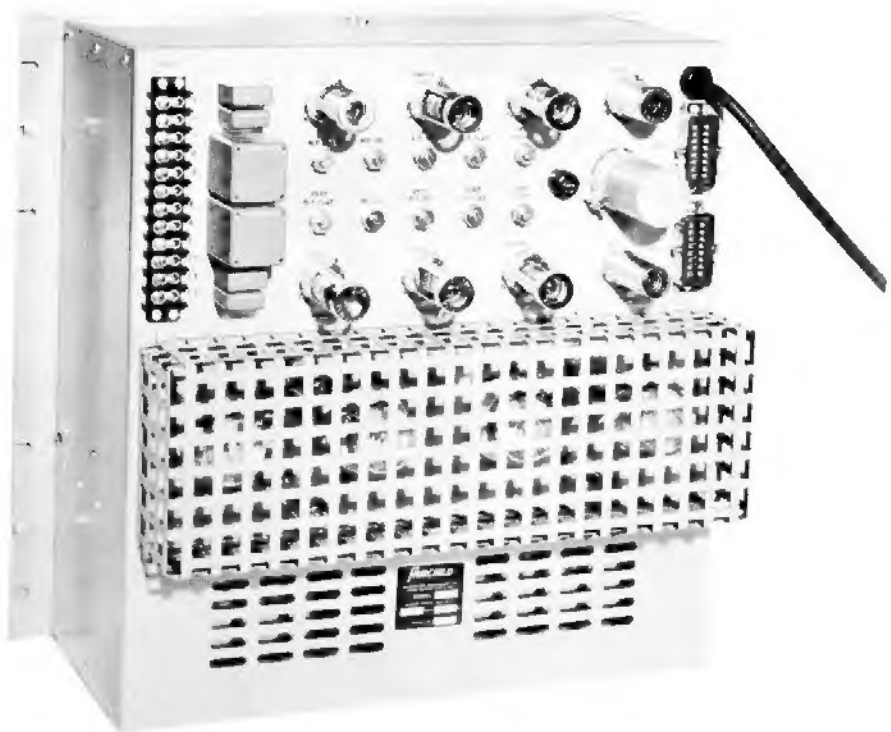


FAIRCHILD
641 STEREO CUTTER SYSTEM
MODEL 642 CUTTERHEAD
MOUNTING DIMENSIONS

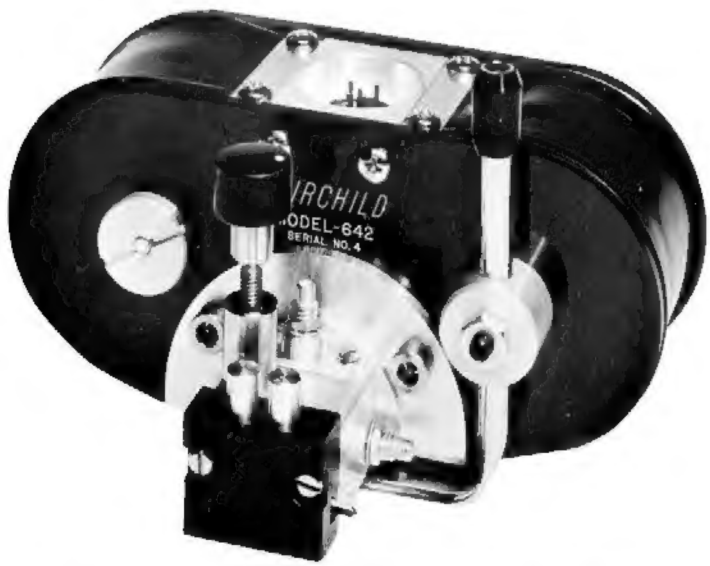




FRONT VIEW - MODEL 644 POWER AMPLIFIER (641 SYSTEM)



REAR VIEW - MODEL 644 POWER AMPLIFIER (641 SYSTEM)



MODEL 642 CUTTERHEAD (641 SYSTEM)

MODEL 643 BETA AMPLIFIER (641 SYSTEM)

REAR VIEW - MODEL 645 POWER SUPPLY (641 SYSTEM)